

Second order filter response with series coupled silica microresonators

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Abstract— We have demonstrated an approach for fabricating a photonic filter with second order response function. The filter consists of two germania-doped silica microtoroidal or microspherical resonators cascaded in series. We use UV irradiation to tune the mode of one microcavity to bring it close to the mode of the second microcavity. This approach produces a filter function with much sharper rolloff than can be obtained with the individual microresonators.

Since their first demonstration by Braginsky et al [1] microspherical resonators with optical whispering gallery (WG) modes have attracted considerable attention in various fields of research and technology. The unique combination of a very high Q $10^8 - 10^{10}$ [2] and submillimeter size makes these resonators attractive candidates for a variety of applications, including fundamental physics, research, molecular spectroscopy [3], narrow-linewidth lasers [4], [5], optoelectronic oscillators [6] and sensors [7]. Effective techniques for coupling light in and out of WG modes have been developed, including the simple method of using angle polished fiber tips [8].

A single microcavity produces a Lorentzian-shaped filter function, and a flatter passband or a sharper rolloff cannot be achieved. There is nevertheless a demonstrated approach based on coupling the resonators in parallel or in series arrangements to obtain a passband that is nearly flat [9] and has a significantly increased out of band signal rejection level; the series coupling has been theoretically demonstrated to yield a better performance than the parallel configuration. In this paper we report on the demonstration of such a configuration using two tunable, coupled microcavities. By tuning the resonance frequency of one cavity very close to the resonance of the second cavity we succeeded in producing a two-cavity compound filter with a nearly top-hat shaped second order filter function.

Recently, the demonstration of such a frequency tuning scheme was reported [10]. To accomplish this tuning, we exploited the photosensitivity of germania-doped silica [11], [12], [13]. When exposed to UV light, this material undergoes a chemical change which alters its index of refraction [11]. This is the same property that is used in writing fiber Bragg gratings [14]. For our case, the change in the index of refraction results in a uniform translation of the resonant frequencies of a microcavity.

In our installation the current to a 1550nm laser diode is modulated with a sawtooth signal to produce a nonlinearly varying frequency with time. To increase the laser power, we use an EDFA at the output of the laser. One half of this output passes through a Fabry-Perot cavity (FSR 20 GHz) which serves as both a reference to correct for any laser frequency drift, and as a scale to measure the spacing between resonance lines. The other half is introduced into

an angle-polished fiber which is the input coupler to the first microcavity. We place a second microcavity near the first, and position it so that the two are coupled. A second angle-polished fiber serves as an output coupler. The light from the output coupler is then routed to a photodiode, so that a plot of current vs. time is obtained as the frequency spectrum of the combined system. Finally, the UV fiber with a convex tip focuses the output of an argon-ion laser onto the surface of the first resonator.

The first resonator was constructed from germania-doped silica, the core material from a germania-doped optical fiber. This material is approximately 19-20 molar % germania. In these experiments, we used both spherical and toroidal resonators. Toroidal resonators are more difficult to make, but have the advantage of a much sparser frequency spectrum [15]. This is because, in a microtorus, the WG modes with trajectories out of the equatorial plane have very high losses, and are effectively removed from the resonator's spectrum. For the second microcavity, we used microspheres of pure silica, with approximately the same diameter as the first cavity. For these resonators, the mode structure of the second cavity remained unchanged throughout the experiment, despite exposure to small amounts of reflected and refracted UV light. Since cavities of similar size will have similar quality factors, the size of a cavity affects the quality of its resonance. Our aim was to produce spectral lines of similar width, to allow the realization of a complex spectral line structure. If the resonances of the two cavities are of greatly differing widths, then as they are made to approach one another, the height of the narrower resonance will simply track the shape of the wider one, which is of no use for this application.

Before starting the experiment, we first arrange for the maximum efficiency in the photochemical process. The maximum efficiency occurs when the UV light is focused just inside the equator of the sphere (or torus), at a point where the WG modes have a large field intensity. To achieve this, we first tune the argon-ion laser to the 379 nm line. This wavelength affects the chemistry of the material, but the process is relatively slow, so the overall effect can be made negligible if the exposure time is kept short. Nonetheless, the absorbed UV in the material results in thermal expansion, which produces a visible shift in the resonance frequencies. If the position of the UV fiber is adjusted such that the thermal shift in the frequency spectrum is a maximum, then the UV light is properly focused at the point of maximum efficiency.

After proper alignment, the laser is tuned to 351 nm, which is the most photochemically efficient wavelength available from our argon laser. To be sure that the sys-

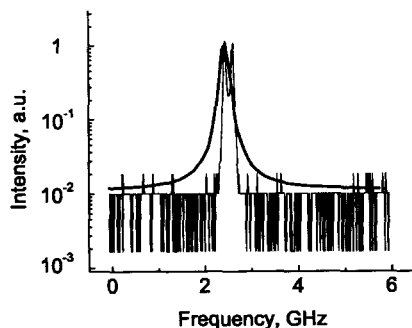


Fig. 1. Filter spectrum. Thin line depicts experimental results, thick line - Lorentzian fit

tem is stable, several data points are first taken with the UV beam blocked. Subsequently, a strobe technique is used by alternately opening and closing a shutter at intervals of several seconds to obtain the spectra. In this way, the frequency shift caused by the transient thermal effects can be separated from shifts caused by a permanent chemical change. Fig.1 depicts final spectrum with its Lorentzian fit from an experiment involving a germania-doped microtorus and a pure-silica sphere. It is important that there is a large distance between resonances (approximately 100 GHz) It is a result of the sparse frequency spectrum of the torus.

In conclusion, we have demonstrated a new technique for Tuning the resonance of a microresonator to produce a coupled system of two microcavities. This system exhibits a second order filter function with a sharp rolloff. We expect that the technique may be used to produced other complex filter functions with any desired line shapes.

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